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## Research on protecting the safety of buildings by using backfill mining with solid

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### Abstract

The coal under buildings accounts for 69% of the total in China, while more than 4.5 billion tons of solid waste is discharged to the ground over years. This paper studied the backfill with solid mining method. It is meaningful for the efficient exploitation of coal mining under buildings as well as reducing environmental pollution around the mining area. In this paper, we analyzed the plastic zone distribution of the face surrounding rock and the variation of surface subsidence systematically. According to the simulation results, backfill mining with solid reduce the damage to the surrounding rock of the goaf and diminish the effect on the stability of surrounding rock. It also can reduce the surface subsidence obviously. Taking the above study results as one of the important references, we research and design the matching equipments with fully-mechanized filling mining. The filling equipments mainly are the self-tamping backfilling hydraulic support and backfilling conveyor. These have been applied to an actual exploitation of coal mining under buildings, and achieved good results. It can control the surface deformation effectively and ensure the safety of buildings and the efficient exploitation of resources. Backfill mining with solid provides a new way for the mining under buildings.

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**Keywords:** Backfill mining with solid; mining under buildings; surface subsidence

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### 1. Introduction

With the development of society and production technology, the demand for mineral resources is increasing. In the condition of mineral resources growing shortage, the exploitation of “three under” mines has a social significance. The coal under buildings reaches 94.68 billion tons, accounting for 69% of the total in China [1]. It seriously affect the normal mine production and resource recycling, shorten the service

life of the mine. On the other hand, more than 4.5 billion tons of solid waste is discharged to the ground over years [2], it will not only take up a lot of land but also pollute the environment. Therefore, the technology of substituting solid waste for coal can serve multiple purposes.

## **2.Requirements and research status of mining under buildings**

Underground mining causes movement of strata and surface. The buildings are subject to different degrees of damage or failure. Therefore, the conditions and methods of mining under buildings must be studied for the full recovery of mineral resources and safety of buildings.

Buildings are generally able to bear a certain degree of surface deformation without apparent damage. The maximum allowable deformation of the building is called critical deformation value. Buildings destruction degree can be determined by the surface deformation value and accordingly identify the different damage grades. So “Buildings, water, railway and main roadway leaving coal pillar and mining coal of holding down regulations” makes the specific damage grades for masonry structure buildings. The surface deformation caused by mining is strictly limited to ensure the safety of the building group.

Surface movement and deformation destroyed the initial balance between buildings and foundations, while the mechanical balance re-established, buildings produced additional stress leading to damage. In the conditions of mastering mining overburden and surface subsidence laws, domestic and foreign scholars develop many measures to control mining overburden and surface subsidence and avoid the damage to buildings. With the development, the measures have technical features, combination of mining and environmental protection. There are Left protected mine pillar method, Underground goaf filling method, Local mining method and Separated layer filling method [3]. In China, the filling mining method and strip mining method is mainly used in mining under buildings in order to reduce damage to buildings. However, the filling mining method can be adapted to a variety of mining conditions comparatively. It's also the only method, which can achieve no underground wastes to surface. Filling mining method can not only reduce the overlying strata damage, but also can reduce the surface movement and deformation significantly. According to the filling power, it can be divided into human filling, wind filling, dry powder filling and water filling [4].

With the development of solid wastes (such as gangue, etc), filling mining method and related equipments, it is widely used in the exploitation of resources under buildings. This method can raise ore produced rate and be adaptable. At the same time, it also can reduce environmental pollution by making use of wastes. The main technical idea is that, throw wastes into the underground through mine drilling and transport to the goaf by transport system, use matching equipment to fill and tamp the goaf as the face of advancing [5]. Ensure the safety of buildings by carrying out the ground pressure management and controlling surface deformation, surrounding rock caving. Gangue as a kind of solid wastes is a relatively low cost of filling materials. Recycling of it can not only protect the environment but also replace the valuable mineral resources [6]. Solid filling mining method must have the appropriate research about laws of strata movement and surface subsidence. However, the majority of filling mining industrial tests carried out in the “three under” conditions, so it is unrealistic to study the strata movement laws entirely depending on the method of actual measurement. For that, MIAO Xie-xing etc. presented the equivalent mining thickness method [7] in solid filling coal mining. The so-called equivalence mining thickness,  $H_z$ , is the maximum mining height after a long period of compaction and rheology. Apply the traditional strata movement and surface subsidence analysis, figure out the surface subsidence value by using  $H_z$ . The value is the largest limiting quantity and just prediction index in engineering practice.

## **3.Establishment of the numerical model**

In order to study the influence of solid waste filling mining method on the safety of buildings, this paper simulates the process of rock movement caused by the mining under buildings and analyzes the distribution of plastic zone on the rock and the variation of surface subsidence systematically. In the numerical simulation process, in order to make the results be closer to the actual situation, this paper makes the necessary assumptions on the mass media, numerical model, geological mining conditions, stress

conditions, mining technology and so on. Ore rock is assumed to be isotropic, homogeneous and consistent with Mohr-Coulumb plastic model media. For underground mining, it is a space problem, and three-dimensional calculation model should be adopted, but in the same conditions, the three-dimensional numerical simulation results are close to the two-dimensional. Therefore, calculation model is simplified to two-dimensional plane model. And the roadways is not considered and simplified as entity.

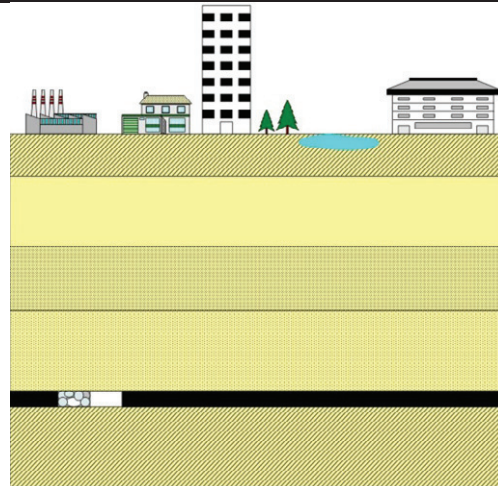
We establish a plane strain model with the FLAC (Fast Lagrangian Analysis for Continuum) numerical calculation software. The constitutive relation of surrounding rock uses Mohr-Coulumb model. Model geometry is  $400 \times 400\text{m}$ , coal seam thickness is 5m, depth is 300m, the total thickness of under overburden is 100m. Face advanced from left to right, excavation step is 10m.

The bottom of model restricts the vertical displacement, the horizontal displacement of the left and right is restricted too. Depending on the height of different buildings, we simulate general plant, high-rise building, and general construction on the surface. To analysis comparatively, we present three simulation schemes: 1. Direct exploitation, 2. Interval filling, 3. Whole filling. The model diagram is shown in Figure 1.

Arrange monitoring points on the surface to monitor surface displacement. And the laws of overburden failure and surface displacement's variation are obtained by numerical simulation. This paper uses rock mechanics parameters of gangue in simulating the fillings.

TABLE I. PHYSICO-MECHANICAL PARAMETERS OF ROCK STRATA IN THE CALCULATION MODEL

| Strata              | $E / \text{GPa}$ | $\sigma_c / \text{MPa}$ | $C / \text{MPa}$ | $\rho / (\text{kg} \cdot \text{m}^{-3})$ | $h / \text{m}$ | $\mu$ |
|---------------------|------------------|-------------------------|------------------|--|----------------|-------|
| Surface soil        | 0.5              | 1.5                     | 1.0              | 2.0                                      | 170            | 0.30  |
| Overlying strata 4  | 20               | 3.3                     | 7.0              | 2.7                                      | 50             | 0.29  |
| Overlying strata 3  | 30               | 3.2                     | 10.0             | 2.7                                      | 40             | 0.22  |
| Overlying strata 2  | 28               | 2.9                     | 8.0              | 2.7                                      | 30             | 0.25  |
| Overlying strata 1  | 20               | 3.5                     | 2.5              | 2.7                                      | 5              | 0.28  |
| Coal                | 1.5              | 1.2                     | 1.56             | 1.4                                      | 5              | 0.30  |
| Underlying strata 1 | 23               | 2.8                     | 4.0              | 2.7                                      | 40             | 0.25  |
| Underlying strata 2 | 25               | 2.7                     | 5.0              | 2.7                                      | 60             | 0.26  |
| Backfill            | 0.1              | 0.007                   | 0.05             | 1.4                                      | 2              | 0.42  |



The model diagram

Scheme 1

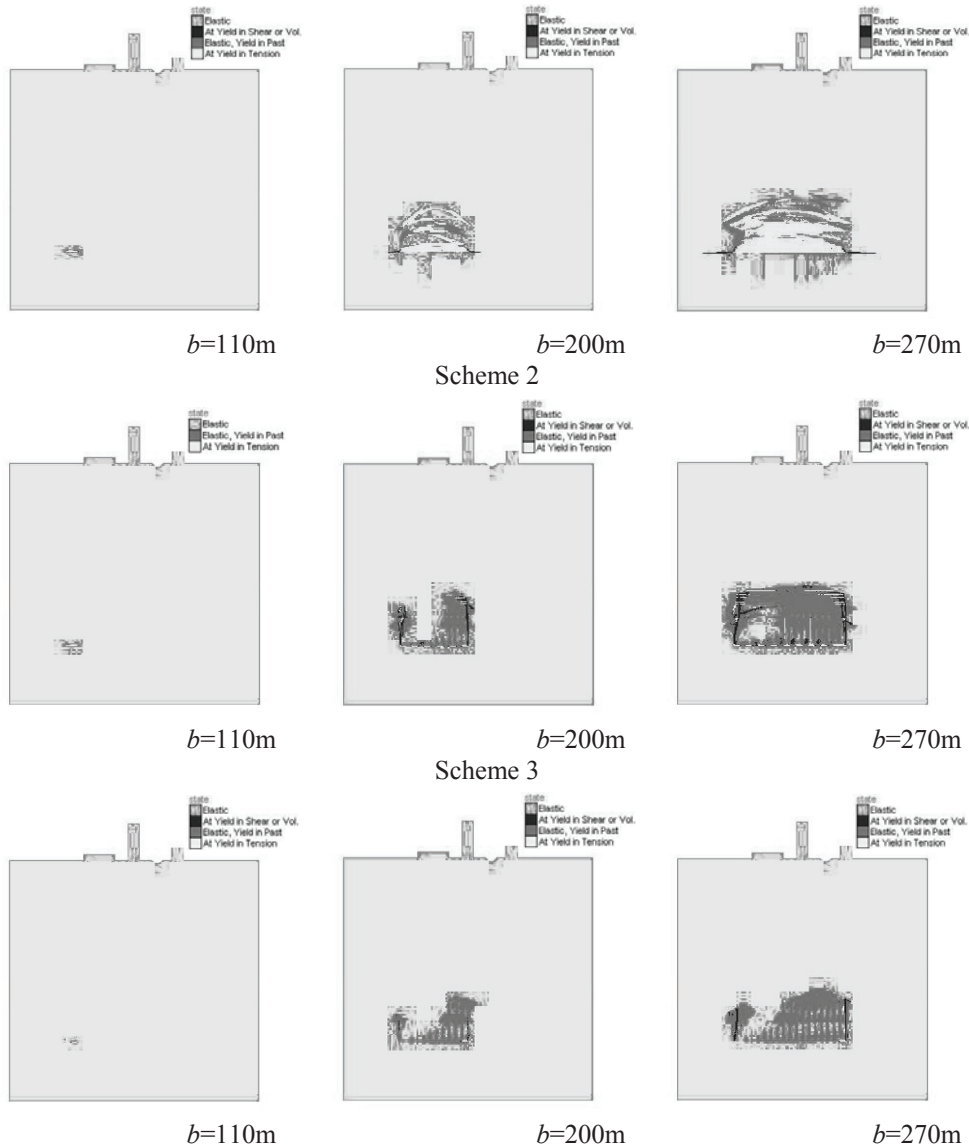


Figure 1. Distribution of plastic zone of three schemes

### 3.1. Distribution of plastic zone

With the face advanced, overlying rock plastic zone distribution of different schemes is shown in Figure.2. For giving prominence to the influence of buildings caused by different mining schemes, we analyze the plastic zone distribution of three schemes when the face forward to 110m, 140m, 200m, 270m, that is just the location where the goaf is under the buildings.

From Fig.2, we can see that, in the mining initial stage, when the face pushed forward to 110m, the face surrounding rock failure conditions is little different for different scheme. With the face advanced, surrounding rock gradually formed a considerable number of damaged units in the scheme 1, and reached

the maximum when the face pushed forward to 280m. The damaged zone on the hanging wall is relatively larger, mainly for the tensile failure and shear failure. The roof has large deformation and displacement is obvious. Comparatively, the backfill in scheme 2 and 3 both reached the plastic limit, and the number of damaged units is smaller. In scheme 3, the damaged units and roof deformation is the least, rarely caving.

It can be seen that, when the overlying strata failure zone is big, its own initial stability must be affected, that directly affect the surface subsidence. And it will pose a direct threat to buildings' security on the surface.

### 3.2. Variations of surface subsidence

Curves of surface subsidence of three different schemes are shown in Fig.3. From Fig.3, we know that

- When the mining field pushed forward to 110m, surface vertical displacement of monitoring point is 894mm in scheme 1, scheme 2 is 418mm, scheme 3 is 392mm. subsidence of scheme 2 is similar with scheme 3, complete filling scheme reduce subsidence 6% than interval filling. But scheme 2 reduces subsidence of 53% than scheme 1, for scheme 3, it reduces 53% than scheme 1. Just according to this data, scheme 2 and scheme 3 almost have the same significant effect in reducing subsidence.
- With the face pushed forward, when the goaf is under ordinary plant, which has a large length, which is just face pushed forward to 140m, surface subsidence of the three simulation schemes are 922mm, 473mm, 410mm respectively. Comparing scheme 2, 3 to scheme 1, effectiveness of reducing subsidence is obvious, ratio of reducing subsidence are 49% and 55%. And filling reduce the amount of surface subsidence 63mm than interval filling, which is essential to the large length buildings which have less ability to bear deformation.
- When face pushed forward to the bottom of high-rise buildings, and the mining field was pushed forward to the 200m, the three simulation schemes of the vertical displacement of the surface monitoring points were 1156mm, 548mm, 464mm. At this point, scheme 3 reduces the amount of rate is 60% than Option 1, the effect of reducing is quite obvious.
- When the mining field pushed under the ordinary construction, the location of mined areas in the 270m, the amount of surface subsidence of different schemes are 967mm, 491mm, 446mm. According to the regulations about mining under buildings, the general buildings damaged level is grade I in the scheme 2, 3. The building damages slightly and has little effect.
- From Fig.3, the trend of scheme 3 curve is more stable, comparing with the others two, without large fluctuations. It shows that the changes of surface subsidence are much less affected by mining, applying no-interval solid filling mining method. The buildings damaged level is below grade I. And the stability of the surface building is more easily guaranteed.

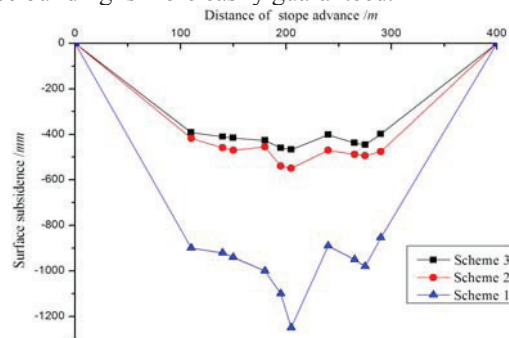


Figure 2. Curves of surface subsidence with the face advanced

Based on the above analysis, the gangue filling mining method can greatly reduce surface subsidence, while the supporting role of backfill can make the overburden not appear overall falling. Overlying strata

movement is controlled well. Surface subsidence is restricted in the maximum limit, effectively ensuring the safety of the surface buildings. However, we should consider the type of surface buildings to choose the specific filling scheme due to that the different damage levels which buildings can bear is different. Ensure that the backfill can play its full role to create the greater economic benefits.

#### 4. Development of the Equipment

Based on the numerical simulation results, the fully-mechanized long wall workface coal mining with gangue filling technology has a good effect on reducing mining subsidence damage and ensuring the safety of the surface buildings. While it also can reduce emissions of coal solid waste, improve resources recovery of the mine, which is one of the key technologies in coal green mining.

This process includes the long wall workface of fully-mechanized coal mining and the goaf filling with gangue two parts. The one of fully-mechanized filling mining key technologies is researching and designing matching equipment. And the coal mining equipment mainly includes shearer and scraper conveyor and so on. The filling equipments mainly are the self-tamping backfilling hydraulic support and backfilling conveyor [8].

##### 1) Self-tamping backfilling hydraulic support

So far, the fully-mechanized coal mining with solid filling hydraulic support has been developed to the fourth generation. The self-tamping backfilling hydraulic mining support is one of the main comprehensive mechanization equipments. It is used with Shearer, scraper conveyor, filling mining conveyors and tamper, which plays a role in management of roof segregating surrounding rock and maintenance of working space. It can self-move forward with scraper conveyor supporting to push the coal face for continuous operation. At the same time it should have the independent tamping mechanism, by using this device to tamp the fillings compactly after the material is filled into the gob. So that the filling material can achieve a certain density based on the backfill reach the roof. The Structure principal sketch of self-tamping backfilling hydraulic support is shown in Figure 4.

##### 2) Backfilling conveyor

The backfilling mining conveyor is made up from scraper conveyor. From the Figure 4 We can see, the backfilling mining conveyor suspends on the back tail beam of the self-tamping backfilling hydraulic support, which has an opening discharge hole at the bottom of the chute. So filling materials can be unloaded to every filling point. The structure principal sketch of the backfilling conveyor is shown in Figure 5.

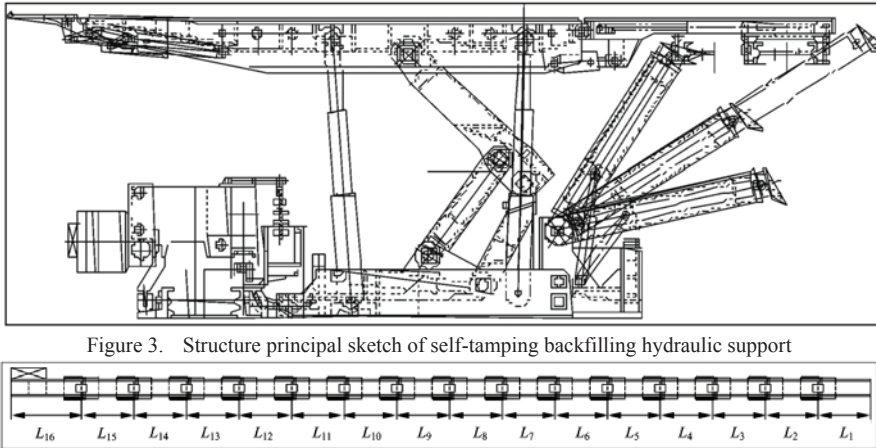


Figure 3. Structure principal sketch of self-tamping backfilling hydraulic support

Figure 4. Structure principal sketch of backfilling conveyor



## 5. Field Measurement

Apply “fully-mechanized coal mining with solid filling technology” in some coal mine, taking a face mining as an example. The basic conditions are that villages, schools and other buildings on the surface, mining depth is 740m, an average mining height is 2m, the surface subsidence prediction and measured are shown in Table II. It can be seen from the Table II, for no-filling mining, the subsidence is down to 1019mm, and easily caused hydrops in the rainy season and other disasters; for gangue filling mining technology, the surface is only slightly deformed, without the housing implementation of reinforcement or repairment. At present, the method is close to full extraction, and the measured surface deformation is small.

TABLE II. ESTIMATION AND IN-SITU MEASUREMENT OF SURFACE MOVEMENT IN WASTE BACK FILLING DISTRICT

| Scheme                                  | Prediction of full seam mining | Prediction of fully-mechanized filling mining | Measurement of fully-mechanized filling mining |
|---|--------------------------------|---|--|
| Maximum subsidence/mm                   | 1019                           | 333   | 18   |
| Maximum horizontal deformation/mm • m-1 | 0.29                           | 0.11  | 0.01   |

## 6. Conclusions

- We establish the plane strain model of resource exploitation under the buildings and simulate the strata movement caused by mining in three different mining schemes. Analyze the distribution of face surrounding rock plastic zone and variation of surface subsidence. According to the simulation results, different mining methods have a significantly effect on the surface subsidence. Comparing solid waste filling mining with direct mining without filling, the former one's destruction elements of the gob surrounding rock is fewer and self-stability is less affected by mining; the filled solid waste occupy the most of space left due to coal mining. The overlying strata movement is controlled effectively. And the amount of the surface subsidence is also reduced obviously, ensuring the safety of the ground buildings.
- Research and design the matching equipments with fully-mechanized filling mining, taking the above study results as one of the important references. Among them, the coal mining equipments mainly include, shearer and scraper conveyor and so on. The filling equipments mainly are the self-tamping backfilling hydraulic support and backfilling conveyor. And the self-tamping backfilling hydraulic support has developed to the fourth generation as one of the main equipments. Apply “fully-mechanized coal mining with solid filling technology” and matching equipments in some coal actual mining. According to the site actual measurements, the surface subsidence is very small. Buildings are only slightly deformed without the housing implementation of reinforcement or repairment.
- Owing to that, different buildings have different abilities of bearing deformation, we must consider the surface conditions of the mining area to choose the specific filling scheme, such as the building intensity and type, mining depth and so on, in order to save costs and create greater economic benefits. Making use of fully-mechanized coal mining with solid filling technology can improve the coal recovery rate under buildings, extend the service life of the mine and achieve a solid waste disposal improving the environment around the mining area. Find out a new technological approach of mining the coal under buildings.

## 7. Acknowledgment

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